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Impact of a new Cherenkov light parameterisation on the reconstruction of shower profiles from Auger hybrid data

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The light signal measured by fluorescence telescopes receives - strongly depending on the shower geometry with respect to the detector - a non-negligible contribution from additionally produced Cherenkov light. This Cherenkov contribution has to be accounted for to determine primary parameters properly. In comparison to the previous ansatz used by other experiments, the impact of a new analytical description of Cherenkov light production in EAS on the Auger event reconstruction is investigated.

1. Introduction

The Pierre Auger Observatory [1] applies the fluorescence technique for calorimetric measurement of longitudinal shower profiles of high-energy EAS. For the determination of primary parameters based on fluorescence observations, a knowledge of the Cherenkov light contribution to the measured light signal is mandatory. The amount of Cherenkov light in the fluorescence detector signal depends on the viewing angle with respect to the shower axis because the Cherenkov photons are emitted mainly in the forward direction. Due to the steep angular distribution of charged particles in a shower only at small viewing angles a significant amount of so-called *direct Cherenkov light* is detected. However, direct Cherenkov light can outnumber the fluorescence light by far. At larger viewing angles, the Cherenkov light contribution is dominated by photons emitted along the shower axis that are scattered into the field of view of the detector. This is illustrated in Fig. 1, where a shower simultaneously detected by two Auger fluorescence telescopes under different viewing angles is shown. As can be seen, one detector receives a large amount of Cherenkov light. Clearly, a precise model of Cherenkov light production is needed to infer the energy E and position of shower maximum $X_{\max}$ of such a shower.

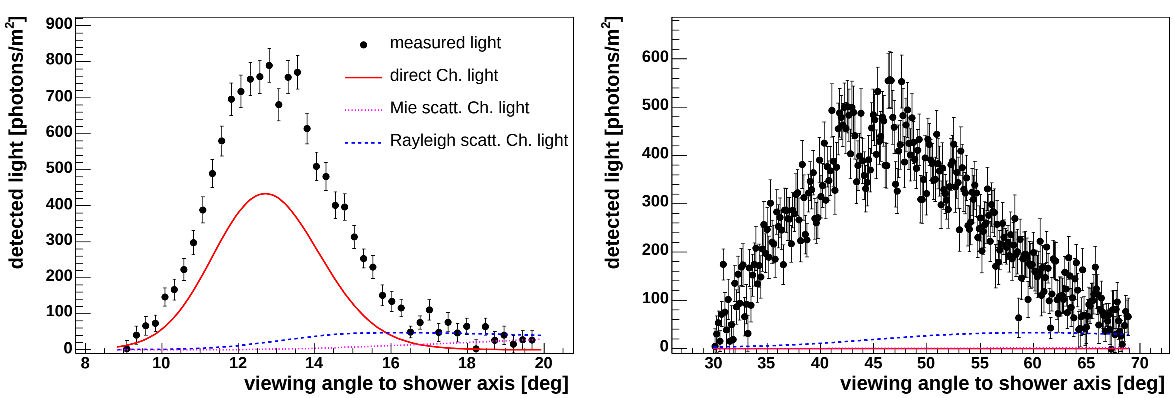

Figure 1. Measured light profiles and reconstructed Cherenkov light of an Auger event observed by two telescopes under different viewing angles (and from different distances).

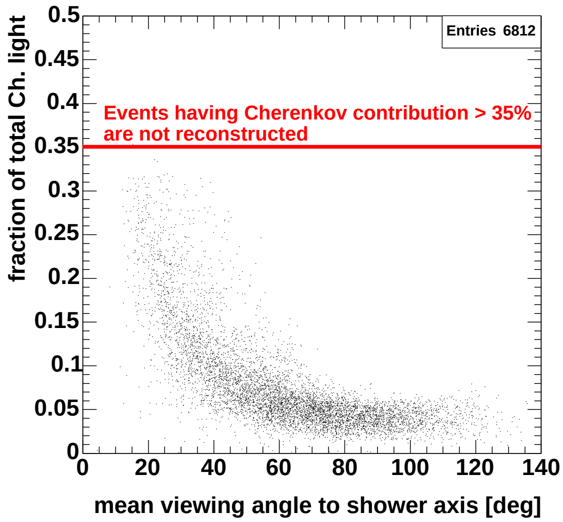

Figure 2. Distribution of reconstructed fraction of Cherenkov light contribution to the total shower signal.

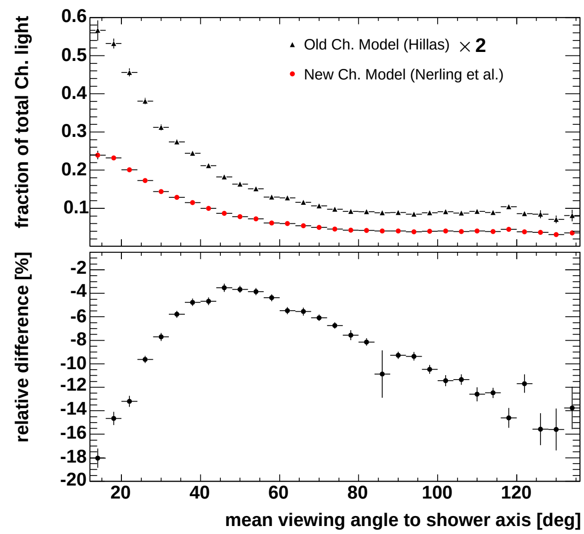

Figure 3. Mean fraction of the reconstructed Cherenkov light contribution. Data points based on the previous Cherenkov model are scaled by a factor of two.

Parameterisations going back to Hillas [2] are typically used for calculating analytically the Cherenkov light contribution to light signals measured in fluorescence observations, see e.g. [3, 4]. Based on CORSIKA [5], QGSJET01 [6] simulations, a new parameterisation of Cherenkov light production providing both the direct and scattered Cherenkov light contributions, has been introduced recently [7].

2. Reconstructed fraction of Cherenkov light

Hybrid fluorescence data from 01/04 to 04/05 have been analysed, using the Auger Offline [8] reconstruction framework, for studying the differences in reconstructed event properties due to the new Cherenkov calculation instead of the one described in [3]. To ensure a reasonable reconstruction quality, the following selection criteria are applied to the data. The χ^2/ndof of the the shower profile fit with a Gaisser-Hillas function is demanded to be less than 3 and the estimated statistical relative uncertainties of reconstructed E and X_{max} are required to be smaller than 30 %. The differences in reconstructed event properties ΔP_{rec} as shown in the following are always calculated on an event-by-event basis as $\Delta P_{\mathrm{rec}} = P_{\mathrm{rec}}(\mathrm{new}) - P_{\mathrm{rec}}(\mathrm{old})$, and relative differences are always given relative to the results of the new Cherenkov model. The viewing angle under which a single event is seen by the detector changes with shower development. Therefore, we define an effective viewing angle as the angle between the normal vector of that triggered pixel having the mean trigger time with respect to the total shower observation time and the shower axis. This mean viewing angle is chosen for the studies presented. From Fig. 2 it can be seen that currently only light profiles with less than about 35 % Cherenkov light are passing the full reconstruction with given quality cuts. In Fig. 3 the reconstructed fraction of total (superposition of direct and scattered) Cherenkov light, defined as $f_{Ch} = N_\gamma^{Ch}/(N_\gamma^{Ch} + N_\gamma^{Fl})$, is shown as a function of the mean viewing angle. Here N_γ^{Ch} is the number of reconstructed Cherenkov photons and $N_\gamma^{Ch} + N_\gamma^{Fl}$ the measured light signal (Cherenkov and fluorescence photons). The application of the new

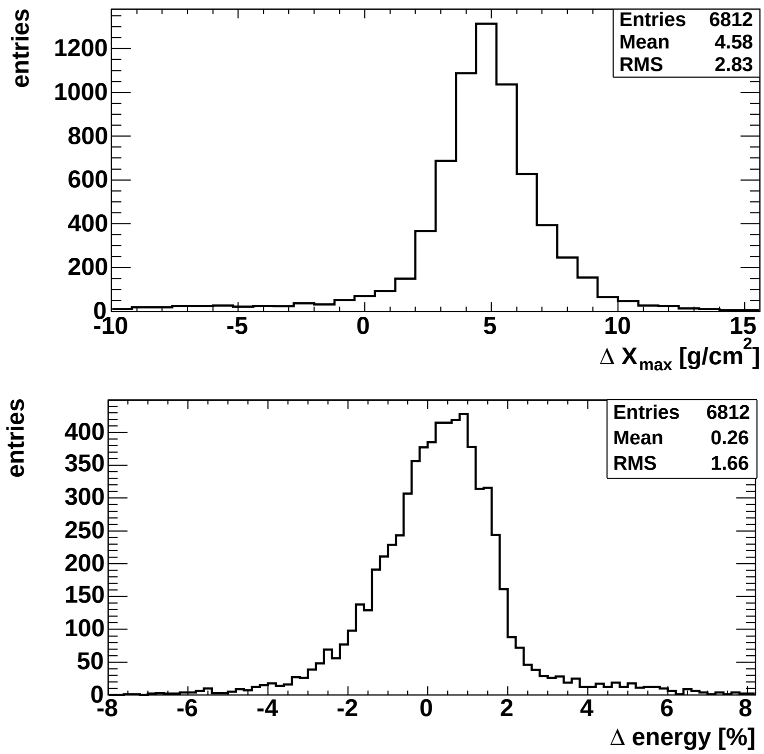

Figure 4. Impact of the new Cherenkov calculation on reconstructed primary energy and position of shower maximum.

model results in smaller fractions of the total Cherenkov light over the whole angular range. The differences range from about -3 % up to -15 % at large viewing angles. For viewing angles smaller than about $40°$, the differences increase strongly, approaching -20 %. They are expected to be even larger for viewing angles smaller than $10°$. However, the comparison is hampered in this phase space by the limited statistics. It can be concluded that the new model predicts significantly less Cherenkov light depending systematically on viewing angle.

3. Impact on reconstructed primary parameters

The impact of the new Cherenkov calculation on the reconstruction of E and $X_{\rm max}$ is shown in Fig. 4 and Fig. 5. The differences in depth of maximum, $\Delta X_{\rm max}$, are given in g/cm^2 and energy, ΔE, in percent. The mean difference averaged over the complete data set amounts to about +5 g/cm^2 and +0.3 %, respectively. As the differences of the reconstructed fraction of Cherenkov light depend on viewing angle, a similar dependence is observed for the primary parameters. This study is shown in Fig. 5, where ΔE and $\Delta X_{\rm max}$ are given versus the mean viewing angle. The difference in reconstructed energy E can be as large as +6 % for smaller angles. The reconstructed depth of maximum increases by about +5 g/cm^2 for viewing angles larger than about $30°$. For viewing angles smaller than about $30°$ the application of the new Cherenkov calculation results in smaller $X_{\rm max}$ values, with the difference increasing up to about -10 g/cm^2 at small viewing angles. For angles smaller than about $10°$, the impact of the new model on inferred primary parameters is expected to be even

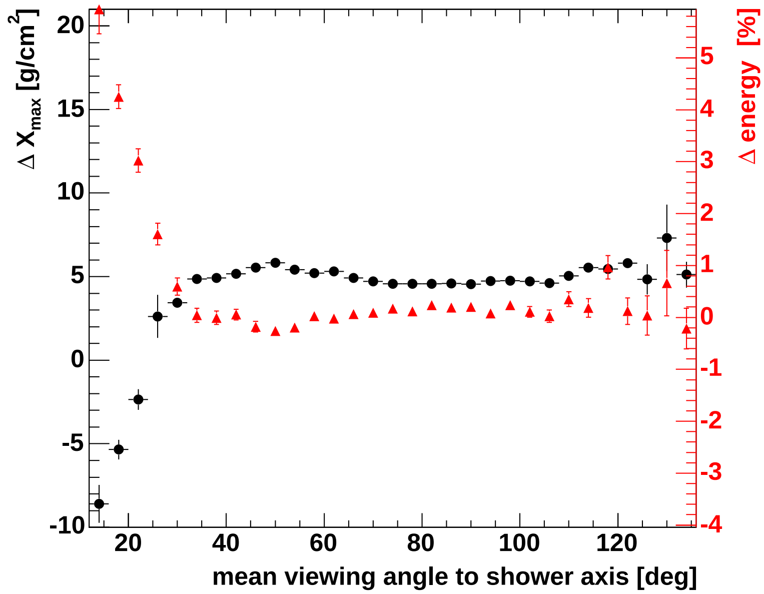

Figure 5. Differences of reconstructed energy and position of shower maximum due to the new Cherenkov calculation as a function of mean viewing angle.

larger. However, currently shower profiles comprising Cherenkov fractions larger than 35 % are rejected in the standard Auger reconstruction.

4. Conclusions

A new Cherenkov light parameterisation [7] has been applied for shower profile reconstruction of the Auger hybrid data. The reconstructed energy and depth of shower maximum have been compared to the traditional treatment [3, 4] on an event-by-event basis. The resulting differences are significant and depend systematically on the viewing angle. Events detected at small viewing angles are more sensitive to the model applied for describing Cherenkov light production.

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